Docket No. 2001-004-TAP

POSITION CONTROL STRATEGY FOR REEL-TO-REEL TAPE DRIVES WITH TWO TACHOMETERS

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates generally to a tape drive system for reading data from and writing data to and from storage media. In particular, the present invention relates to a method and apparatus for controlling the position of tape in reel-to-reel tape drives.

2. Background of the Invention:

Magnetic tape is a widely used data storage media. Tape drives and their corresponding tape media are applied to data storage tasks in all levels of computer data storage from personal computers to workstations to mainframes and supercomputers. Tape products are available in many formats from many vendors in a wide range of cost categories ranging from less than one hundred to many ten's of thousands of dollars.

Automated tape media handling systems complement tape drives and have become commonplace in the data storage industry by offering the increased performance of tape cartridge loading and unloading robotically in and out of tape drives. Automation has turned magnetic tape from an "off-line" storage device requiring human intervention (typically taking minutes) to load and

unload tape to a more "near online" system termed "nearline" (typically taking seconds). Nearline tape systems combine the desirable low cost of tape storage with access times longer than traditional "online" disk or solid state based data storage systems but fast enough to meet many online performance requirements with lower storage cost. With the nearline class of storage and the speed of robotics, the tape drive's access time, the time to load a tape cartridge then locate and access its data, has become a significant performance parameter.

To respond to the demands of the competitive marketplace it is vital to develop and offer products that have the highest performance at the lowest cost. Design trade-offs are made to balance cost against performance.

To increase access time performance at a lower cost, reel sizes (radii) must be reduced and initial load of the tape must be done at the midpoint of tape (equal tape length on each reel) such that data can quickly be accessed in either direction. Reduced reel sizes allow for smaller reel motors, amplifiers, and power supply to be used. Additionally, smaller cooling fans and simpler non-pneumatic tape paths are used. All of this "miniaturization" aids in increasing access time and in lowering cost. Further cost reduction and simplification measures include cheaper and more flexible reel motor couplings and fewer feedback sensors (i.e., no tape tension transducer).

These simpler reel-to-reel tape drives with flexible motor coupling and no tension transducer may fail while

in tachometer position control and while reading/writing short records or moving a small distance. The symptom for these failures is typically loss of tension and it occurs while pulling the tape from a small radius reel of tape onto a large radius reel. In these drives and earlier drives, the reel position is always controlled with respect to a common reference reel irrespective of the direction of motion. This common reference reel is arbitrarily designated as the file reel and the other reel as the machine reel.

Position control in these reel-to-reel tape drives is inherently difficult due to the lack of tension transducer to cut down tension oscillations during position maneuvers. There is a tendency of the tape to stick to various tape path surfaces in a stopped condition due to lack of air in the tape path. When the tape is stuck to a tape path surface, the required current to move the tape along the surface during attempted acceleration is increased. Static friction currents are difficult to predict. A mismatch, between an applied current to overcome the friction and very low speed conditions, contributes to the position loop instability.

Therefore, it would be desirable to have a method and apparatus to increase the performance of reel-to-reel tape drives with an improved position control strategy.

SUMMARY OF THE INVENTION

The present invention provides a removable media system, such as a tape drive system, with improved performance. In a preferred embodiment, a method and apparatus is disclosed to provide an enhanced and unique position control strategy, which improves performance through the reduction of position tracking errors in a tape drive system.

The present invention provides a method, apparatus, and computer instructions for controlling tape movement in a tape drive system. The direction of tape movement is determined with respect to a file reel and a machine reel. If the direction of tape movement is toward the file reel, the tape is moved using machine reel control and if the direction of tape movement is toward the machine reel, the tape is moved using file reel control (see **Figure 2**).

The present invention also provides an alternative method, apparatus, and computer instructions for controlling tape movement in a tape drive system using a file radius and a machine radius to control the tape movement. In this method, the size of a file reel, designated as the file radius, and the size of a machine reel, designated as the machine radius, are determined. If the machine radius is smaller than the file radius, tape motion is carried out using machine reel control and if the file radius is equal to or smaller than the machine radius, tape motion is carried out using file reel control.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 is a block diagram of the components of a reel-to-reel tape drive system in accordance with a preferred embodiment of the present invention;

Figure 2 is a block diagram of the original operation mode using file reel position control for a reel-to-reel tape drive in accordance with a preferred embodiment of the present invention;

Figure 3 is a block diagram of the original operation mode using file reel position control for a reel-to-reel tape drive in the beginning of tape position in accordance with a preferred embodiment of the present invention;

Figure 4 is a block diagram of the operation mode with the new position control strategy for a reel-to-reel tape drive according to the present invention;

Figure 5 is a flowchart of the position control strategy according to the present invention;

Figure 6 is a block diagram which demonstrates the center-of-tape condition for a reel-to-reel tape drive in

accordance with a preferred embodiment of the present invention;

Figure 7 is a block diagram of the operation mode with another position control strategy for a reel-to-reel tape drive according to the present invention;

Figure 8 is a flowchart of another position control strategy according to the present invention; and

Figure 9 is a graph of position tracking error for the file reel control mode and the switched control mode with respect to time according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference now to the figures and in particular to **Figure 1,** a block diagram of the components of a reel-to-reel tape drive system is depicted in accordance with a preferred embodiment of the present invention. Reel-to reel tape drive system **100** is an example of a tape system in which the present invention may be implemented. The tape drive system contains magnetic tape **105**, which is connected from file reel **110** to machine reel **115**. Read/write head **120** stores and retrieves data from the tape. Tachometer **125**, tachometer **130**, motor 135, and motor **140** are attached to file reel **110** and machine reel **115**, respectively, by motor shafts (not shown). Tachometers **125** and **130** send data signals to digital signal processor (DSP) controller **145**, which routes the signals through amplifiers **150** and **155**.

In the depicted examples, tachometers **125** and **130** are implemented using encoders. An encoder senses and indicates rotation of the motor shaft. One such position encoder uses Hall-effect devices to sense the movement of magnetized areas on the motor shaft. The Hall-effect device provides a phase and quadrature signal indicating speed and displacement of the motor shaft. These signals have an AC component that varies about a DC offset level. The AC component varies as a function of position. For example, the AC component may be a sinusoid, where each period of the sine wave indicates a certain amount of

shaft displacement. To position file reel **110** or machine reel **115**, DSP controller **145** determines the actual position based on position encoder signals received from the encoders and moves the motor to position the reel to the desired position. The amplifiers change the level of the signal generated by DPS controller **145** for use by motors **135** and **140**.

Turning next to **Figures 2A** and **Figures 2B**, block diagrams of the operation mode with file reel position control for a reel-to-reel tape drive as currently used are depicted in accordance with a preferred embodiment of the present invention.

In **Figure 2A**, the beginning of tape (BOT) condition occurs when most of the tape is located on file reel **200**. A forward motion, as indicated by arrow **210**, is performed with file reel control. The encoder associated with motor for file reel **200** causes tape **230** to be pushed on machine reel **220** with file reel position control. The end of tape (EOT) condition occurs when almost all of the tape is on machine reel **260**. In **Figure 2B**, a backward motion, as indicated by arrow **250**, of tape **270** causes tape **270** to be pulled onto file reel **240** with file reel position control.

Continuing to **Figures 3A** and **3B**, a block diagram of the current operation mode using file reel position control for a reel-to-reel tape drive in the beginning of tape position is depicted in accordance with a preferred embodiment of the present invention.

In **Figure 3A**, tape **300** is pushed in a forward motion, as shown by arrow **310**, from file reel **320** to

machine reel **330** in the BOT condition. In **Figure 3B**, tape **340** is pulled in a backward motion, as illustrated by arrow **350,** to file reel **360** from machine reel **370** in the BOT condition. Failures have been observed when the tape is in file reel position control while moving in the backward toward BOT direction near the BOT. Pulling tape onto a large radius reel, such as BOT, while the file reel position is controlled, contributes to instability.

The present invention provides a method and apparatus to use file reel position control while moving in the forward direction and switching to machine reel position control while the tape motion is in the backward direction. Loss of tension occurs more frequently when accelerating from zero velocity while pulling tape onto a large radius reel. The position control strategy is improved by using the machine reel to perform the backward motion by pushing the tape onto the file reel rather than having the file reel pull the tape. The present invention recognizes that slow and small movements may cause static friction. A greater current is needed to move tape when static friction is present.

The mechanism of the present invention changes the reel that controls the tape movement. The reel controlling the tape movement also is referred to as the control reel. This reel is the one from which position information is gathered via the encoder and used to move the tape. For example, if the file reel is used for control, the control is referred to as file reel control. If the machine reel is used for control, this type of control is referred to as machine reel control. The

change is such that the control reel always pushes tape. The mechanism avoids having the control reel pull tape and reduces the possibility of tape breakage or loss of tension. The changing of the control reel also is referred to as a switched-mode control.

Turning next to **Figures 4A** and **4B**, block diagrams of the operation mode with a switched-mode control strategy for a reel-to-reel tape drive as described in accordance with a preferred embodiment of the present invention. The positioning system of the present invention illustrated in these figures may be implemented within reel-to reel tape drive system **100** in **Figure 1.**

In **Figure 4A**, tape **400** is pushed in a forward motion as indicated by arrow **410**, from file reel **420** to machine reel **430** in the BOT position. In this direction, the encoder and motor associated with file reel **420** are used to control the positioning of tape **400**.

When the direction of the tape changes, the mechanism of the present invention uses the machine reel control for the backward motion, as indicated by arrow **440** in **Figure 4B.** In other words, the control of this motion is provided through the encoder and motor associated with machine reel **430**, rather than the encoder and motor associated with file reel **420**. In particular, the position control signals are sent to the motor for machine reel **430**. Thus, tape **400** is pushed in backward motion **440** from machine reel **430** to file reel **420** in the BOT position. Pushing tape onto a large radius reel, such as BOT, is a stable operation as compared to pulling tape onto such a large radius reel.

As illustrated in **Figures 4A** and **4B**, the reel controlled in moving tape is such that the tape is always being pushed relative to the control reel.

With reference now to **Figure 5**, a flowchart of switched-mode control strategy is depicted in accordance with a preferred embodiment of the present invention. The process illustrated in **Figure 5** may be implemented in a controller such as digital signal processor controller **145** in **Figure 1**.

The process begins with a determination as to whether the tape is to be moved backward or forward (step **500**). Backward movement occurs if the machine reel is to push the tape. If the tape is to be moved in a backward motion, then machine reel control is selected (step **510**). Tape movement is then controlled by using the machine reel to push the tape from the machine reel to the file reel (step **520**) with the process terminating thereafter.

Turning back to step **500**, if the tape is to be moved in a forward motion, then file reel control is selected for use in tape movement (step **530**). Then, file reel control is used to push the tape from the file reel to the machine reel (step **540**) with the process terminating thereafter. As can be seen, the reel used to control tape movement is changed such that the reel selected for use in controlling tape movement always causes the tape to be pushed from the control reel to the other reel.

Turning next to **Figure 6**, a block diagram which demonstrates the center-of-tape condition for a reel-to-reel tape drive is depicted in accordance with a preferred embodiment of the present invention. Another

way to implement the switched-mode control and to avoid pulling tape onto a reel of large radius when that reel is the control reel is switching the control reel at the center-of-tape (COT). **Figure 6** shows the center-of-tape (COT) condition when half of tape **600** is located on file reel **610** and the other half of tape is located on machine reel **620**. The file reel radius (FileRadius) and the machine reel radius (MachineRadius) are equal at this point.

With reference now to **Figures 7A** and **7B**, block diagrams of an operation mode with another switched-mode control strategy for a reel-to-reel tape drive are depicted in accordance with a preferred embodiment of the present invention. In this example, the switching depends on the relative reel radii or the relative size of the reels. The positioning of the present invention illustrated in these figures may be implemented within reel-to-reel tape drive system **100** in **Figure 1**.

In **Figure 7A**, tape **700** is pushed in a forward motion as indicated by arrow **710**, from file reel **730** to machine reel **740** in the position where the MachineRadius is less than the FileRadius. In this situation, the encoder and motor associated with machine reel **740** are used to control the positioning of tape **700**, i.e. machine reel control is used.

As the tape motion continues in the forward direction, as shown by arrow **710** and when the FileRadius becomes smaller than the MachineRadius just as the COT position is crossed, the mechanism of the present invention switches to the file reel control for the

continued forward motion, as indicated by arrow **710** in **Figure 7B**. In other words, control of the motion is provided through the encoder and motor associated with file reel **730**. The file reel control in forward direction, as depicted by arrow **710** in **Figure 7A**, continues until the machine becomes full, i.e. EOT condition is reached. As the direction of motion of tape changes from forward direction of arrow **710** to backward direction of arrow **720** as shown in **Figure 7B**, file reel control is still continued for backward direction, as depicted by arrow **720**.

As the tape motion continues in the backward direction of arrow **720** in **Figure 7B**, and as soon as the MachineRadius becomes smaller than the FileRadius, the position control is switched to machine reel control, as indicated by arrow **720** in **Figure 7A**.

The present invention recognizes that the machine reel control of tape motion in the backward direction of arrow **720** and forward direction **710** in **Figure 7A** takes place as long as the MachineRadius is smaller than the FileRadius. Similarly, file reel control of the tape motion in the forward direction of arrow **710** and backward direction of arrow **720** in **Figure 7B** is carried out as long as the FileRadius is smaller than or equal to the MachineRadius.

In this switched-mode control, any pulling of tape onto a control reel or pushing of tape out of a control reel takes place when that reel has a size less than or equal to one half of the maximum reel size. In this way,

pulling of tape onto a control reel of large radius and associated stability problem is completely avoided.

Turning next to **Figure 8**, a flowchart of another switched-mode control strategy where the switching of control reel depends on the reel size is depicted in accordance with a preferred embodiment of the present invention. The process illustrated in **Figure 8** may be implemented in a controller such as digital signal processor controller **145** in **Figure 1**.

The process begins with a determination as to whether the MachineRadius is smaller or equal to the FileRadius (step **800**). If the MachineRadius is smaller than the FileRadius, then machine reel control is used irrespective of direction of tape motion (step **810**) with the process terminating thereafter. Otherwise, file reel control is used independent of the direction of tape motion (step **820**) with the process terminating thereafter.

With reference now to **Figure 9**, a graph of position tracking error for the file reel control mode and the switched control mode as described in the present invention with respect to time with either method of implementation. Graph **900** shows test results of position tracking error for the switched control strategy. The data displayed in line **910** represents the switched control strategy compared to the file reel control. With respect to time, file reel control data is represented by line **920**. Data from this test validates the present invention using switched control mode as generating less position tracking error.

The present invention is important in controlling tape movement because of the critical need to be able to perform rapid starts and stops on tape drive systems to ensure high performance during position control. The present invention enables rapid starts, stops, repositioning, and achievement of full functionality for tape drives.

It is important to note that while the present invention has been described in the context of a fully functioning tape drive system, those of ordinary skill in the art will appreciate that the processes of the present invention are capable of being distributed in the form of a computer readable medium of instructions and a variety of forms and that the present invention applies equally regardless of the particular type of signal bearing media actually used to carry out the distribution. Examples of computer readable media include recordable-type media such as a floppy disk, a hard disk drive, a RAM, CD-ROMs, and transmission-type media, such as digital and analog communications links.

The description of the present invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for

various embodiments with various modifications as are suited to the particular use contemplated.